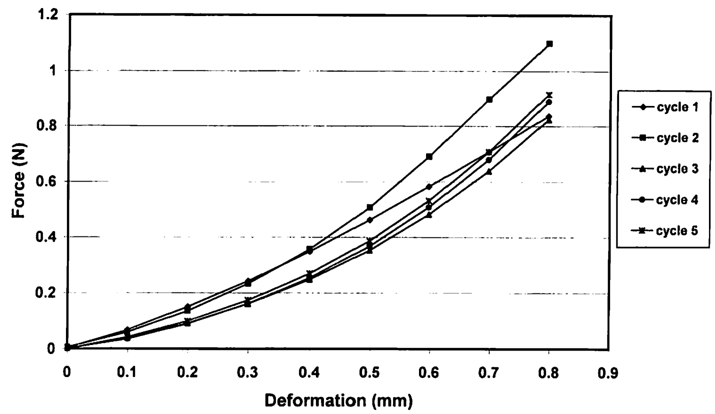

Figure 7. Force-deformation curves for fruit #4. Compression cycles 1 and 2 were performed 25 s apart. Subsequent cycles were performed at 15-min intervals.

Conclusions

There is potential to non-destructively assess blueberry firmness using parallel flat plates. Compression <1.0 mm in the equatorial direction produced smoother and more consistent force- deformation curves than in the longitudinal direction. Four compression cycles at the same location of a fruit were necessary to produce force-deformation curves that are similar in shape and deformation energy levels, and from which firmness parameters may be extracted. This non-destructive technique shows promise for evaluating postharvest quality changes in blueberries and merits more extensive testing.

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Literature Cited

Ferraz, A. C. O., S. A. Sargent, and A. J. Fox. 2000. Delays to cooling and postharvest quality of fresh, Florida blueberries. Proc. Fla. State Hort. Soc. 113:268-271.

Ferreira, M. D., S. A. Sargent, J. K. Brecht, and C. K. Chandler. 1995. Strawberry fruit temperature affects sensitivity to bruising from impact and compression forces. HortScience 30:791. (Abstr.).

Proc. Fla. State Hort. Soc. 114:142-144. 2001.

CHARACTERIZATION OF FRESH TOMATO AROMA VOLATILES USING GC-OLFACTOMETRY

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Abstract. **Important volatile compounds contributing to the aroma of fresh tomatoes were determined and identified using gas chromatography-olfactometry (GC-O) and gas chromatography-mass spectrometry (GC-MS) techniques. Three panelists sniffed the aroma volatiles on the GC-O, as the compounds were being eluted. Aromas were detected from a total of 23 compounds. Out of these, 15 compounds have been previously identified as important contributors to fresh tomato aroma. These compounds are: 2+3- methylbutanol, 1-penten-3-one, hexanal, *cis*-3-hexenal, *trans*-2-hexenal, *cis*-3-hexenol, *trans*-2-heptenal, 1-octen-3-one, 6-methyl-5-hepten-2-one, 2-isobutylthiazole, phenylacetaldehyde, methylsalicylate, 2-phenylethanol, geranylacetone, and ß-ionone. Furthermore, furaneol, linalool, methional, citral, and *trans, trans*-2,4-decadienal were all odor-active and may also contribute to fresh tomato aroma. The remaining three compounds could not be identified. Their aroma descriptors ranged from rancid and medicinal to green and floral.**

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Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular items of fresh produce in the United States and is second only to potatoes in per capita consumption and total dollar value among vegetables. The characteristic sweet-sour tomato flavor is believed to be a result of complex interactions between the volatile aromatics and the non-volatile sugars and acids (Petro-Turza, 1987). Investigators have emphasized the importance of both volatile components (Baldwin et al., 1998; 2000; Buttery et al., 1989; Krumbein and Auerswald, 1998) and sugars and acids (Malundo et al., 1995; Stevens et al., 1979).

Around 400 aroma compounds have been identified in fresh tomatoes (Petro-Turza, 1987). Various odor threshold studies have shown that only a few of these compounds are significant contributors to fresh tomato aroma (Buttery and Ling, 1993; Buttery et al., 1987; 1989), being present in concentrations greater than 1 µl/L. Included in this category are:

cis-3-hexenal, ß-ionone, hexanal, ß-damascenone, 1-penten-3-one, 2+3 methylbutanol, *trans*-2-hexenal, 2-isobutylthiazole, 1-nitro-2-phenylethane, *trans*-2-heptenal, phenylacetaldehyde, 6-methyl-5-hepten-2-one, *cis*-3-hexenol, 2-phenylethanol, 3-methylbutanal, methylsalicylate, and geranyacetone (Buttery, 1993; Buttery and Ling, 1993). In addition, furaneol (Buttery et al., 1995), hexanol, methional, and 1-octen-3-one (Krumbein and Auerswald, 1998) may also contribute to fresh tomato aroma. There is no single aroma impact compound present, rather it is a combination of all these compounds that gives tomato its aroma and flavor.

Gas chromatography-olfactometry (GC-O) is a useful tool to determine the odor potency of the compounds in a food system. Aroma extract dilution analysis (AEDA) (Grosch, 1993) and Charm analysis (Acree, 1993) are two common quantitative GCO procedures used to determine the potent odorants in food. There have only been a few investigations carried out to study tomato aroma by GC-O. Hayase et al. (1984) studied tomato aroma using GC-O and concluded that hexanal, *trans*-2-hexenal, geranylacetone, 2-isobutylthiazole, and farnesylacetone were important components of fresh tomato aroma. Recently, Krumbein and Auerswald (1998) studied fresh tomato aroma using GC-O and AEDA and concluded that *cis*-3-hexenal, hexanal, methional, 1-octen-3-one, 1-penten-3-one, and 3-methylbutanal were the most odor-active volatiles in fresh tomatoes.

Materials and Methods

Tomato fruit. Tomatoes at red-ripe stage were purchased locally in Winter Haven, Fla.

Extraction of aroma volatiles. A modified dynamic headspace method of Buttery et al. (1987) was used. A 200-g sample of tomatoes were blended for 30 s and the mixture was held for 3 min. This was followed by adding 200 ml of saturated calcium chloride and blending again for 10 s. The mixture was placed in a round bottom flask and a Tenax trap (300 mg Tenax TA, 60-80 mesh) was attached to the flask. The mixture was gently heated at 40°C with continuous stirring. Nitrogen gas (150 ml/min) was used to sweep the headspace of the tomato blend and carried it through the Tenax trap. This isolation was carried out for 180 min. The trap was then removed and volatiles extracted with 10-15 ml acetone. The final sample was concentrated with nitrogen flux to a volume of 10 µl.

GC-MS analysis. The analysis of the volatile compounds was made using a Agilent model 5973N MSD mass spectrometer with a 7683 autosampler and model 6890 gas chromatograph equipped with a 30 m × 0.25 mm HP-5 (cross-linked Phenyl-methyl siloxane) column with 0.25 mm film thickness (Agilent, Palo Alto, Calif.). The initial oven temperature was held at 40°C for 5 min. The temperature was then increased at the rate of 10°C/min to a final temperature of 220°C and held there for 5 min. The injection port and ionizing source were kept at 250°C and 280°C, respectively. The split ratio was 10:1 and the injection volume was 2 µl. There was a solvent delay of 2 min. The mass spectrum was collected from 35 m/z to 300 m/z generating 5.27 scans/s. Compound identifications were made by comparison of the mass spectra and retention times with those of corresponding standards.

GC-Olfactometer. GC-O analysis was carried out using a Hewlett-Packard 5890 Series II plus chromatograph equipped with a 30 m × 0.25 mm HP-5 (cross-linked phenyl-methyl siloxane) column with 0.25 µm film thickness (Hewlett Packard, Palo Alto, Calif.). The column was directly connected to the flame ionization detector as well as the sniffing port (Gerstel, Inc., Baltimore, Md.). The injector and detector temperatures were maintained at 250°C and 280°C respectively. The oven temperature parameters were the same as described above for the GC-MS. Humidified air was added to the sniffing port at 100 ml/min and a 2-ml sample was injected with a split ratio of 10:1. Three panelists were asked to detect the odors by pushing down on a lever and verbally describing the odor active components in the tomato extract. Three replications were made for each panelist. The retention times of the compounds were determined using the FID mode and these were compared to the olfactometry runs. Turbochrom data system (PE Nelson, San Jose, Calif.) was used to collect all data.

Results and Discussion

A total of 71 compounds were identified in the dynamic headspace of the tomato extract, using GC-MS. These compounds have been reported previously by Petro-Turza (1987) and are among the 400 or so volatile compounds identified in tomatoes. GC-O was carried out as a means to separate the odorless compounds from the odor-active volatile compounds. GC-olfactometry showed 23 compounds that were odor-active in the tomato extract (Table 1). There were 9 aldehydes, 3 alcohols, 6 ketones, 1 ester, 1 sulfur-containing compound and 3 compounds that were not identified.

The C_6 compounds, commonly known as "green" compounds: hexanal, *cis*-3-hexenal, and *trans*-2-hexenal were described as having a floral, grassy and green odor. 6-methyl-5-hepten-2-one, phenylacetaldehyde, 2-phenylethanol, citral, and ß-ionone were all described as having a floral aroma. On the other hand, 3-methlybutanal, *cis*-3-hexenol, and 2-isobutylthiazole had pungent and rancid aromas, whereas *trans, trans*-2,4-decadienal had medicinal and chalky odor. 4-hydoxy-2,5-dimethyl-3(2H)-furanone, also known as furaneol, had a very distinct caramelized odor, whereas 1-octen-3-one had an earthy, mushroomy odor. Methional had a very distinct potato odor and geranylacetone was described as having an earthy aroma. Of the unidentified compounds, two were responsible for medicinal and rancid aromas (RT = 12.44 and 16.45 min) and one compound had a green, floral aroma (RT = 25.55 min). Figure 1 shows a FID chromatogram and the corresponding aromagram for the tomato sample.

Some of these compounds have previously been reported as being important contributors to fresh tomato aroma. Compounds such as the C_6 "greens", *trans*-2-heptenal, 3-methylbutanal, geranylacetone, 2-isobutylthiazole, ß-ionone, 6-methyl-5-hepten-2-one, and 1-penten-3-one are considered as important components of tomato aroma and have been extensively studied (Baldwin et al., 1998; Buttery et al., 1989; Krumbein and Auerswald, 1998; Tandon et al., 2000). Lately, a few other compounds are emerging as possibly being important to fresh tomato aroma. In this work, 1-octen-3-one (mushroomy), furaneol (caramel-like), linalool (perfume-like), methional (potato), citral (floral), and *trans, trans*-2,4-decadienal (medicinal) have been found to be odor-active and thus probably are important contributors to tomato aroma. Buttery, et al. (1995) have previously mentioned that furaneol may contribute to tomato aroma. Likewise, Krum-

Table 1. Odor-active volatiles and their aroma descriptors in fresh tomatoes.

Compound	Retention time	Descriptors
3-Methylbutanol	2.45	Pungent, earthy
1-Penten-3-one	3.31	Grassy, herbal
Hexanal	5.30	Fresh, floral, herbal
cis-3-Hexenal	5.52	Green, grassy, sweet
trans-2-Hexenal	7.15	Green
cis-3-Hexenol	7.47	Almonds, medicinal, pungent
Methional	8.50	Potato, pungent, sharp
trans-2-Heptenal	10.25	Dried fruits
1-Octen-3-one	10.42	Earthy, soil, mushroom
6-Methyl-5-hepten-2-one	11.24	Floral, green
2-Isobutylthiazole	11.54	Fermented, pungent
Phenyacetaldehyde	12.02	Floral, musky, rose
Unknown	12.44	Medicinal, rancid
4-hydroxy-2,5-dimethyl-3(2H)-Furanone (Furaneol)	12.52	Caramel, burnt
Linalool	13.22	Sweet, perfume-like
2-Phenylethanol	13.35	Floral, sweet
Methylsalicylate	14.38	Plastic, pesticide
Citral	15.37	Floral
trans, trans-2,4-Decandienal	16.02	Medicinal, chalky
Unknown	16.45	Musty, medicinal, pungent
Geranylacetne	17.33	Earthy
ß-ionone	19.22	Floral, perfume-like, candy
Unknown	25.55	Green, floral

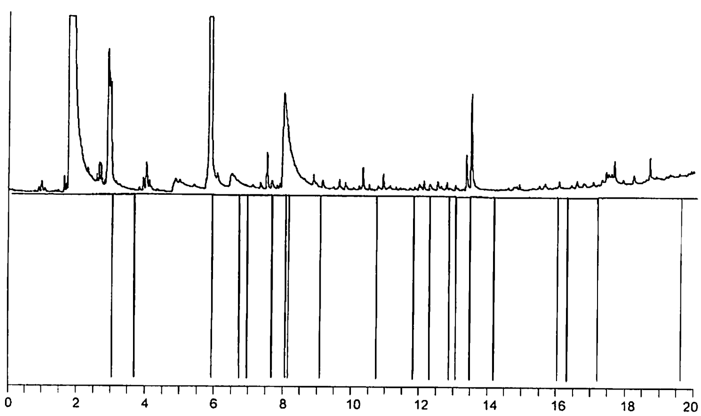

Figure 1. GC (top) and GCO (bottom) example chromatograms of fresh tomato homogenate headspace.

bein and Auerswald (1998) have concluded that 1-octen-3-one is one of the most important odor-active volatile in fresh tomato, but linalool, citral, and *trans, trans*-2,4-decadienal have not been previously implicated as important aroma imparting compounds in tomatoes.

Sensory descriptors of these compounds as they exit individually from the sniff port do not necessarily relate to their sensory contribution when mixed with other volatiles, tomato pulp, sugars, and acids in terms of chemical reactions and for human perception. The interactive effects, such as demonstrated by Tandon et al. (2000) could not be assessed in this study.

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Literature Cited

Acree, T. E. 1993. Bioassays for flavor, p. 1-20. In: T. E. Acree and R. Teranishi (Eds.), Flavor Science: Sensible Principles and Techniques. Amer. Chem. Soc., Washington, D.C.

Baldwin, E. A., J. W. Scott, M. A. Einstein, T. M. M. Malundo, B. T. Carr, R. L. Shewfelt, and K. S. Tandon. 1998. Relationship between sensory and instrumental analysis for tomato flavor. J. Amer. Soc. Hort. Sci. 123:906-915.

Baldwin, E. A., J. W. Scott, C. K. Shewmaker, and W. Schuch. 2000. Flavor trivia and tomato aroma: Biochemistry and possible mechanisms for control of important aroma components. HortScience. 35:1013-1022.

Buttery, R. G. 1993. Quantitative and sensory aspects of flavor of tomato and other vegetables and fruits, p. 259-286. In: T.E. Acree and R. Teranishi (Eds.), Flavor Science: Sensible Principles and Techniques. Amer. Chem. Soc., Washington, D.C.

Buttery, R. G. and L. C. Ling. 1993. Volatile components of tomato fruit and plant parts: Relationship and biogenesis, p. 22-34. In: R. Teranishi, R. G. Buttery, and H. Sugisawa (Eds.). Bioactive Volatile Compounds from Plants. ACS Symp. Series, No. 525, Amer. Chem. Soc., Washington, D.C.

Buttery, R. G., R. Teranishi, and L. C. Ling. 1987. Fresh tomato aroma volatiles: A quantitative study. J. Agr. Food Chem. 35:540-544.

Buttery, R. G., R. Teranishi, R. A. Flath, and L. C. Ling. 1989. Fresh tomato volatiles: composition and sensory studies, p. 213-222. In: R. Teranishi, R. G. Buttery, and F. Shahidi (Eds.). Flavor Chemistry Trends and Developments, ACS Symp. Series No. 388. Amer. Chem. Soc., Washington, D.C.

Buttery, R. G., G. R. Takeoka, and L. C. Ling. 1995. Furaneol: Odor threshold and importance to tomato aroma. J. Agr. Food Chem. 43:1638-1640.

Grosch, W. 1993. Detection of potent odorants in foods by aroma extract dilution analysis. Trends Food Sci. Technol. 4:68-73.

Hayase, F, T. Y. Chung, and H. Kato. 1984. Changes of volatile components of tomato fruits during ripening. Food Chem. 14:113-124.

Krumbein, A. and H. Auerswald. 1998. Characterization of aroma volatiles in tomatoes by sensory analyses. Nahrung 42:395-399.

Malundo, T. M. M., R. L. Shewfelt, and J. W. Scott. 1995. Flavor quality of fresh tomato as affected by sugar and acid levels. Posthavest Biol.Technol. 6:103-110.

Petro-Turza, M. 1987. Flavor of tomato and tomato products. Food Rev. Intl. 2:309-351.

Stevens, M. A., A. A. Kader, and M. Albright. 1979. Potential for increasing tomato flavor via increased sugar and acid content. J. Amer. Soc. Hort. Sci. 102:724-731.

Tandon, K. S., E. A. Baldwin, and R. L. Shewfelt. 2000. Aroma perception of individual volatile compounds in fresh tomatoes (*Lycopersicon esculentum*, Mill.) as affected by the medium of evaluation. Postharvest Biol. Technol. 20:261-268.